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A COMPARISON OF THE RECORDS OF TWO ANEMOMETERS AT DIFFERENT HEIGHTS AT SOUTHPORT

By W. C. KAYE, B.Sc.

The International Meteorological Committee adopted at Vienna in 1926 a scale giving in miles per hour and metres per second the equivalents of the Beaufort numbers of wind force. The values on this scale apply on land to the speeds at a height of 6 metres above a level surface free from all obstructions. Such an exposure is known as the standard exposure. It was also decided by the Committee that in cases where the exposure of an anemometer differed from the standard one in a manner such that the effect is known either by practical experiments or straight-forward deduction from well-established results, the records of the anemometer should be converted to the Beaufort scale by an appropriate table.

In the British Isles the heights of anemometers are usually greater than 6 metres being mostly a little above or below 10 metres or 33 ft. The values suitable for use with an anemometer at an " effective height " (see explanation below) of 33 ft. can be deduced from the standard international table by the use of Hellmann's formula for the variation of speed with height, viz.—

$$V = K\,[1{\cdot}00 + 2{\cdot}81 \log (h + 4{\cdot}75)]$$

where V is the speed, h the " effective height " of the anemometer in metres and K is a constant. The values so obtained agree closely with the values which had been in use in this country for many years before the international decision was made and this table has been adopted for normal application to anemometers in the British Isles. It is used without modification for all anemometers for which the values derived from the international tables would not differ by more than 5 per cent from the values of the 33 ft. table. In the case of anemometers for which such values differ from the 33 ft. tables by more than 5 per cent a different table must be made using the " effective height " of the anemometer under consideration and Hellmann's formula.

It is necessary to state here what is meant by the term " effective height ". The " effective height " of an anemometer is the estimated height at which the anemometer would record an equal mean velocity in an open situation free from obstructions. Thus when converting the velocity shown by an anemometer into Beaufort force it is necessary to take into consideration the nature of the exposure of the anemometer. To obtain the Beaufort equivalent for any particular anemometer one must therefore have (1) the scale of equivalents for the " effective height " 10 metres, (2) the formula giving the variation of the wind speed with height in an open situation and (3) the " effective height " of the particular anemometer under consideration.

The " effective height " of an anemometer is estimated by taking into account the surroundings and the effect of obstructions on the speed of the wind. The effective height is always less than the actual height.

[*To face p. 2*

FIG. 1.—SOUTHPORT ANEMOGRAPH STATION.
(facing north)

The present note collects together the results of the comparison at Marshside, Southport, of two anemometers of different heights. The head of one was at a height above ground of 59 ft. and an assumed effective height of 50 ft. The other anemometer was erected with its vane at a height of 42 ft. and an assumed effective height of 33 ft. (10 metres).

The object of the comparison was to test the validity of Hellmann's formula for variation of wind with height when applied to a coastal exposure. Mr. Joseph Baxendell, the Southport Borough Meteorologist, had expressed doubt in regard to the application of this formula (which was derived by Hellmann from observations over grass land at Nauen) to cases of wind off the sea. He considered there would be comparatively little variation of velocity with height between 40 and 60 ft. in these circumstances and thought that the application of a reduction formula to the 59 ft. anemometer would result in the publication of misleading information in regard to the frequency of gales at Southport. It was therefore decided to investigate the matter directly by comparing the records of the 59 ft. instrument with those of a second instrument erected with its vane at the standard height. The observations were carried out by Mr. Baxendell and his observers while the evaluations from the records were done by Mr. Charles Baxendell.

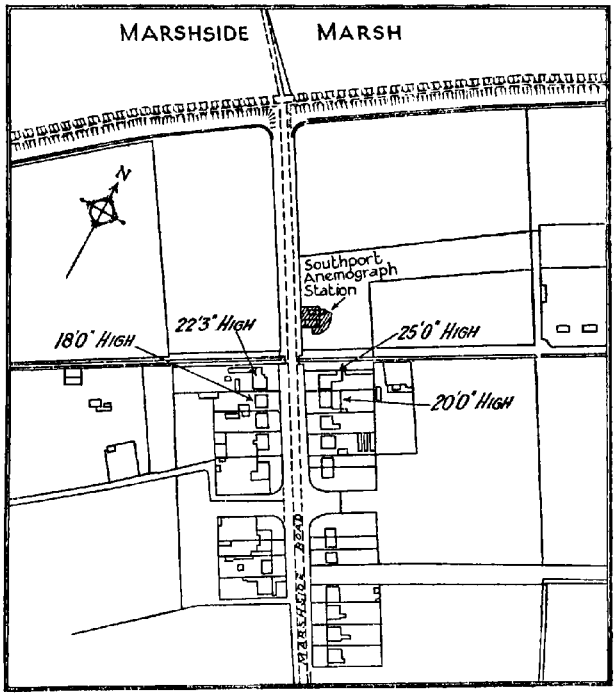

FIG. 2.—PLAN SHOWING POSITION OF SOUTHPORT ANEMOGRAPH STATION.

The Marshside anemometer station is situated about two miles from the sea, which lies to the north-west. There are cottages to the south-east, while the whole town of Southport lies to the southward, so that winds from south and south-east are sheltered at the lower levels. There is open flat land to north, north-east and east, while the winds from off the sea blow from north-west, west and south-west. The direct sea wind (from north-west) is, Mr. Baxendell states, always deflected slightly upwards by the sea-wall. A photograph (taken with the camera pointing north) of the anemometer station and a plan showing the immediate surroundings of the station with the heights of the nearest buildings are reproduced. The sea embankment, which is about half the height of the buildings, is also shown. Both the photograph and the plan were kindly supplied by Mr. Baxendell.

It was originally intended, after a series of comparative readings at the two heights had been obtained, to take a series with the two anemometers at the same height in order to provide the means of eliminating any instrumental differences between the two anemometer systems. It was, however, found inconvenient to take a series of comparative readings with the anemometers at the same height and it was eventually decided to exchange the recorders with reference to their heads every month, and by taking means of pairs of months to eliminate more or less the instrumental differences of the recorders.

With the monthly exchange of recorders with reference to their heads, results were obtained for four summer months and four winter months giving the value of $(V-v)/V$ (where V is the mean velocity at 59 ft. and v the mean velocity at 42 ft.) for different directions.

The results are given in Table I and are shown graphically in Fig. 3. All winds under 10 m.p.h. were excluded.

TABLE I

Direction	N.	NE.	E.	SE.	S.	SW	W.	NW.	Arithmetic mean of the 8 directions
$(V-v)/V$ for May, June, July, Aug., 1934	·057	·037	·010	·087	·127	·063	·040	·060	·060
$(V-v)/V$ for Nov., Dec., 1934, Jan., Feb., 1935	·069	·058	·021	·113	·108	·070	·051	·079	·071

Hellmann's formula taking the actual heights of the two anemometers (59 ft. and 42 ft.) gives $(V-v)/V$ as ·07, or taking the effective heights of the two anemometers as 50 ft. and 33 ft.

$(V - v)/V$ is ·08. Broadly speaking, the results given in Table I suggest that Hellmann's formula is not inappropriate to the Southport exposure.

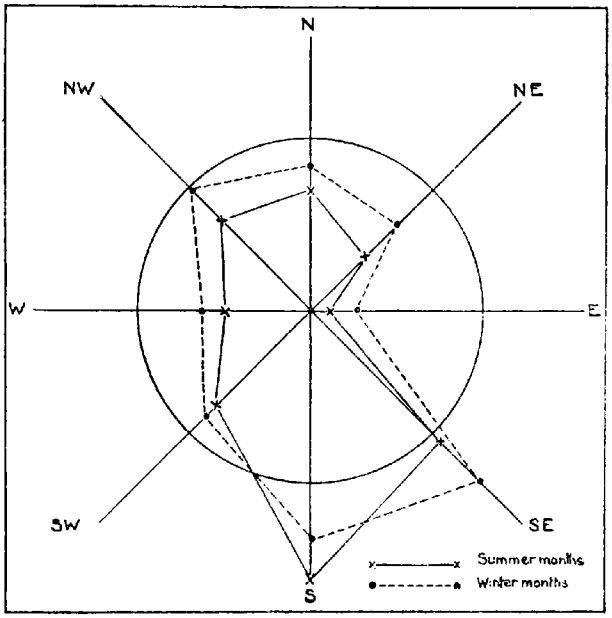

FIG. 3.—VARIATION WITH WIND DIRECTION OF $(V-v)/V$.
The radius of the circle is equivalent to $(V-v)/V = \cdot 08$ which is the value derived from Hellmann's formula, taking effective heights as 50 ft. and 33 ft. respectively.

These results also seem to show that the winds from the sheltered directions give much the largest increase of speed with height. The built-upon area extends over the south-east and south and some of the south-west direction. The sea embankment to the north-west shows a smaller effect. The increase of speed with height is, on the whole, greater in winter than in summer. The remarkably low value of $(V - v)/V$ for east winds, if genuine, is difficult to explain and may possibly be due to an insufficient number of cases.

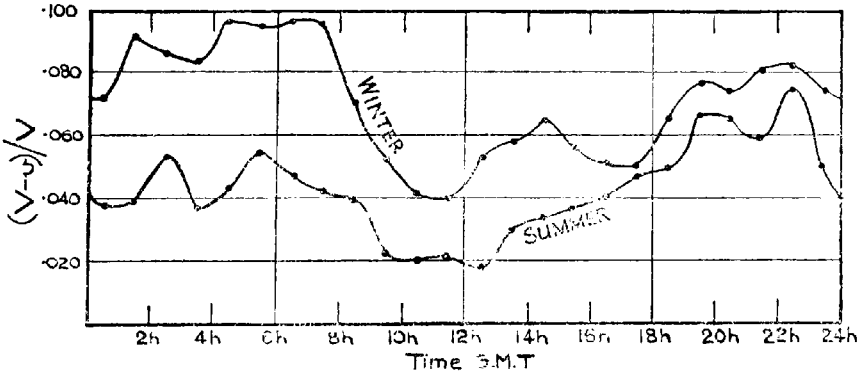

FIG. 4.—DIURNAL VARIATION OF $(V-v)/V$.

In Table II is given the value of the ratio $(V - v)/V$ for the diurnal variation for all directions combined. This diurnal variation was obtained by taking mean hourly values for the four summer and four winter months. The results are given graphically in Fig. 4.

TABLE II—VALUES OF $(V - v)/V$

Hour G.M.T. (60 minutes ending at)	1	2	3	4	5	6	7	8	9	10	11	12
Summer (May, June, July, Aug., 1934)	·038	·039	·053	·037	·042	·055	·047	·043	·040	·022	·020	·021
Winter (Nov., Dec., 1934, Jan., Feb., 1935)	·071	·091	·086	·083	·096	·094	·096	·094	·070	·052	·042	·040
Hour G.M.T. (60 minutes ending at)	13	14	15	16	17	18	19	20	21	22	23	24
Summer (May, June, July, Aug., 1934)	·019	·030	·033	·036	·040	·047	·049	·066	·065	·059	·074	·050
Winter (Nov., Dec., 1934, Jan., Feb., 1935)	·053	·058	·065	·056	·051	·050	·065	·076	·074	·080	·081	·075

MEAN :—Summer, ·043 ; Winter, ·071.

The summer curve of the diurnal variation of $(V - v)/V$ shows a sudden drop between 8h. 30m. and 9h. 30m., presumably due to the setting in of the diurnal coastal sea breeze. The daily minimum is reached between 12h. and 13h., after which the value rises hour by hour up to between 19h. and 20h. This corresponds with the disappearance of the temperature lapse rate as the sun is going down and the beginning of the building up of the night inversion. The value remains more or less the same until about 23h., when the nocturnal land breeze sets in and the value falls to as low as ·038 in the early hours. There is a slight rise before sunrise with a secondary maximum between 5h. and 6h., and then the value decreases with the setting in of convection until the minimum between 12h. and 13h.

In the winter curve the summer land and sea breeze effects are absent. The hourly winter values run from an average of about ·09 between 2h. and 8h. to ·04 between 10h. 30m. and 11h. 30m. The mean value of $(V - v)/V$ is much larger for the winter than the summer, being ·071 as against ·043.

The means in Tables I and II are different. The reason for this difference is that the number of observations for each wind direction is not the same. In Table II the mean is $\Sigma_1^N x_n/N$ where x_n is an individual value and N is the total number of such values. In Table I the mean is $\Sigma\bar{x}_{m_1}/M$ where $\bar{x}_{m_1}$ is the value of $\Sigma_1^{m_1} x_n/m_1$ for a given direction and M is the number of divisions of wind direction. Hence

$$\frac{\Sigma\bar{x}_m}{M} = \frac{\frac{\Sigma_1^{m_1} x_n}{m_1} + \frac{\Sigma_1^{m_2} x_n}{m_2} + \frac{\Sigma_1^{m_3} x_n}{m_3} + \cdots\cdots}{M}$$

which would equal $\Sigma x_n/N$ if all the m's were equal which they are not.

The next stage in the investigation was suggested by Lt. Col. Gold, who considered that information was required as to the variation of $(V - v)/V$ with speed as well as with direction and that it might be that the apparent variations with direction were really due to variation with speed.

It was necessary for this purpose to choose months of sufficient windiness to give the necessary ranges of velocity and the four months January, February, September and October, 1935, were used. The winds were split into four velocity groups and two direction groups (*a*) sheltered land winds (SE. and S.), (*b*) sea winds (SW., W. and NW.). The results are given in Table III.

TABLE III

	Sheltered land winds (SE. and S.)			Sea winds (SW., W. and NW.)			
Speed	10–19 m.p.h.	20–29 m.p.h.	30–39 m.p.h.	10–19 m.p.h.	20–29 m.p.h.	30–39 m.p.h.	40 m.p.h. & over.
$(V - v)/V$ ..	·147	·165	·214	·079	·070	·068	·064

(No winds of 40 m.p.h. or above were recorded from S. or SE.)

From these figures it will be seen that the ratio $(V - v)/V$ becomes progressively less for sea winds as the wind speed increases although fairly good agreement is obtained with the value derived from Hellmann's formula (·08 taking the assumed effective heights). On the other hand, with sheltered land winds the value of $(V - v)/V$ becomes progressively greater as the wind speed increases and is much in excess of the ·08 derived from Hellmann's formula, being twice as large in the speed range 20–29 m.p.h. and over $2\frac{1}{2}$ times as large in the range 30–39 m.p.h. The values are indeed much higher than one would have expected from an inspection of Table I.

It is of interest to compare some of the foregoing results with the results obtained at Cardington in 1930 from the comparison of the 150 ft. and 50 ft. anemometers.* Owing to the lie of the land the

**London, Geophys. Mem. No. 54,* 1932.

difference in height of the two anemometer heads was 132 ft., while the anemometers were about a thousand yards apart. For Cardington, using the mean hourly wind values, the ratio $(V - v)/V$ (where V is the velocity at the higher anemometer and v the velocity at the lower anemometer) is as follows :—

	Summer.	Winter.
10h.–15h.	·108	·100
22h.–3h.	·254	·142

(Value derived from Hellmann's formula = ·20.)

This may be compared with the figures from Southport obtained from Table II. The value of $(V - v)/V$ for Southport is as follows:—

	Summer.	Winter.
10h.–15h.	·024	·052
22h.–3h.	·052	·081

(Value derived from Hellmann's formula = ·08.)

In the case of both Cardington and Southport $(V - v)/V$ is greater by night than by day. At Cardington, however, the values in summer are greater than in winter whereas at Southport the reverse is the case.

The table below gives the value of $(V - v)/V$ for ranges of speed at Cardington for the whole year 1930 during the periods 10h.–15h. and 22h.–3h.

TABLE IV

	10h.–15h.				22h.–3h.			
Speed	10–19 m.p.h.	20–29 m.p.h.	30–39 m.p.h.	40 m.p.h. or over.	10–19 m.p.h.	20–29 m.p.h.	30–39 m.p.h.	40 m.p.h. or over.
$(V-v)/V$	·066	·152	·183	·231	·207	·171	·172	·196

This may be compared with Table III which gives the Southport values of $(V - v)/V$ for sheltered land winds and for sea winds over the different speed ranges. It will be seen that $(V - v)/V$ increases with the speed of the wind in the case of Cardington day winds as well as with Southport sheltered land winds, whereas the increase is not shown either with the Cardington night winds or the Southport sea winds.

In conclusion it is perhaps desirable to summarize the Southport results by taking specific values of velocity for the 59 ft. anemometer (effective height 50 ft.), applying Hellmann's formula to reduce them to the values for the 42 ft. anemometer (effective height 33 ft.) and comparing these reduced values with the values of v obtained from

the ratio $(V - v)/V$ under the various conditions described in the paper. The following results are obtained :—

	m.p.h.	m.p.h.	m.p.h.	m.p.h.
Sea winds				
Speed at higher anemometer ..	45	35	25	15
Speed at lower anemometer by reduction by Hellmann's formula ..	41	32	23	14
Speed at lower anemometer derived from values of ratio $(V - v)/V$ for sea winds (Table III)	42	33	23	14
Sheltered land winds (SE. and S.)				
Speed at higher anemometer	35	25	15	
Speed at lower anemometer by reduction by Hellmann's formula	32	23	14	
Speed at lower anemometer derived from values of $(V - v)/V$ for land winds (Table III)	28	21	13	

Night and day winds in winter and summer

Assuming gusts of 80 m.p.h., 60 m.p.h., and 40 m.p.h. on the higher anemometer and using the values of $(V - v)/V$ for summer and winter for the periods 10h.–15h. and 22h.–3h. given above, we get the following results :—

	m.p.h.	m.p.h.	m.p.h.
Gust at higher anemometer	80	60	40
Gust at lower anemometer from Hellmann's formula	74	55	37
Gust at lower anemometer derived from $(V - v)/V$ for 10h.–15h., summer ..	78	59	39
Gust at lower anemometer derived from $(V - v)/V$ for 10h.–15h., winter ..	76	57	38
Gust at lower anemometer derived from $(V - v)/V$ for 22h.–3h., summer ..	76	57	38
Gust at lower anemometer derived from $(V - v)/V$ for 22h.–3h., winter	74	55	37

Thus, at Southport in the case of sea winds and also of winter night winds, the speeds obtained at the lower anemometer from the observed mean values of $(V - v)/V$ agree almost exactly with those obtained by using Hellmann's formula. In the case of sheltered land winds, the speeds at the lower anemometer derived from the values of $(V - v)/V$ are a little lower than those calculated by Hellmann's formula especially in the case of the stronger winds. For summer day winds the speeds got from $(V - v)/V$ are greater than those derived from the formula, as they are (but not to such an extent) in the case also of winter day and summer night winds. On the whole it may be said that the application of Hellmann's formula to the Southport exposure gives results which are suitable for ordinary meteorological purposes.

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